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Quantitative risk analysis on an FSO crude oil storage tank

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Abstract

The industry of oil and gas are blooming in a rapid rate as time goes by because of the massive use of fuel oil and natural gas in this age of time. However, as more fuel oil are produced the industry is moving away from onshore to offshore and towards the ultra-deep-water region, where vessel like FSOs are introduced. FSO are short for Floating Storage and Offloading which are vessels used in deep water operation. The FSO plays an important role in the business where a single disastrous incident will affect the industry and the company. The focus of the research will be on the FSO that holds million barrels of crude oil. In this work, fire risk analysis is used to assess the crude oil storage tank on a typical FSO as this is a relatively new mode in exploration and production (E&P) activity. By calculating the individual risk per annum (IRPA) and potential loss of life (PLL), methods are introduced to mitigate fire risk on FSOs. The results show that the level of failure is low and requires less action for the FSO crude oil storage tank to stay safe during operation in the offshore environment.

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1.0 Introduction

The oil and gas industry have been changing over a few decades. It is also responsible in supplying over 57% the world energy consumption (Baxter et al., 2008). This ever-changing industry has been going on strong and requires more sources as time goes by. This includes tackling the deep-water with harsh sea condition at unreachable location, which is how FSO (Floating, Storage and Offloading) was introduced (Christodoulou, 2015). The deep-water exploration and production (E&P) had gradually increased from 9% in 2014 to more than 25% in 2015 (Oyeneyin, 2015).

Fig. 1 shows a typical FSO structure that is used for storing and offloading of crude oil. There is no production equipment on FSO unlike FPSO. They are used when pipeline transportation is difficult especially in the deep-water region (IHI Corporation, 2013). FSO are made from tankers without the engines to propel themselves, hence they moved by using tow boats. The vessel operates in an area for more than 10 years and will docked once in every few years for inspection and maintenance.

FSO plays a big part in the oil and gas industry especially when it comes to deep-water operation and its ability to store crude oil before offloading it into a

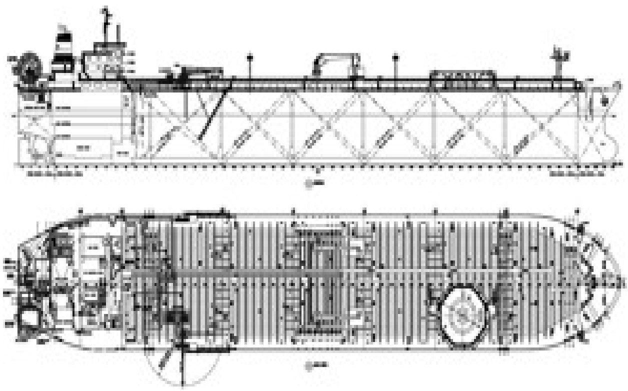

Fig. 1 : Typical FSO vessel

tanker. These vessels directly increase the amount of deep-water and ultra-deep-water wells that could not be accessed before this. Normally moored and attached to multiple wells, the FSO makes for a more coherent platform for storage and processing of oil as the vessel is designed to handle harsh sea conditions and can even disconnect its mooring system during extreme weather events. Quantitative risk analysis or known commonly as QRA is the analysis of risk from events that are hazardous. It is then used to form an evaluation in aiding decision making especially on how to eliminate and control the hazard. QRA is also sometimes called 'probabilistic risk assessment' or 'probabilistic safety analysis' (Spouge, 1999). Since the FSO is considerably new in oil and gas E&P operation and most FSO are made from converting old cargo tankers into FSO, hence there is a definite similarity in the cargo storage design (Spouge, 2017).

In order to establish a control measure against all possible hazards, quantitative risk assessment need to be made. The risk analysis is used to provide insight to the operators on the risk that involved. The objective of this research is to identify the potential hazardous event/accident that could occur on the FSO. The potential hazards were then analyzed to measure the level of risk. The analysis was conducted to examine the possible effect of any planned activity and to estimate the loss in case of an accident. Finally, control measures were recommended for eliminating/ controlling the hazard. By doing so, suitable measures can be proposed to ensure the minimization of the effect.

2.0 Concept of risk and risk analysis

2.1 Risk

Commonly referred as the product of likelihood and severity, risk is the potential where personnel will be hurt or will be affected in terms of their health if hazard are exposed to them. It is also applicable to equipment breakdown and even effects the environment negatively. Table 1 shows the risk matrix used from the Malaysian Department of Health and Safety (DOSH).

2.2 Hazard

According to DOSH Malaysia (Department of Occupational Safety and Health), hazard itself is source or a situation with a potential for harm in terms of human injury or ill health, damage to property, damage to the environment or a combination of these. Hazards arises when a task or equipment is used and could directly lead to harmful effects towards health and the company itself.

2.3 Accident

The word accident brings suggestion that a particular event that happen out of prediction but does not happen as random event and occur due to a particular source (Loimer et al., 1996). In case of FSO, accidents in workplace are a very disturbing problem for personnel. In a year alone, almost 1.03 million workers have been experiencing injuries due to accident in their workplace (Simpson et al., 2005). Workplace accident has been around since forever and some of the most common reasons behind them are:

- *Stress and fatigue*. Human errors will increase when they cannot operate with focus. Stress and fatigue will disturb personnel focus because they will be distracted from the job.
- *Unsafe acts*. Sometimes employees would like to use shortcuts by doing something out of the norm to make their work easier. This might be dangerous and might not follow the HSE requirements for the safety of workplace.
- *Machine/Tools*. If the machineries are not well serviced and replaced after a long run, it might act up and become a workplace hazard.

From 1980 to 2013, there is in total of 88 confirmed tanks explosion. Table 1 shows the severities of fire related incidents on trading tanker over 80,000 dwt (deadweight tonnage) from the year 1980 till 2013. Although the number is high, the peak of the occurring accidents happens around 1986, and has been decreasing since then. The lower number of accidents however minimizes itself to only serious accidents (Spouge, 2017).

FSO is a very important sector in the production of hydrocarbon in oil and gas industry. On an FSO, million barrels are stored at the refinery underneath hundreds of personnel’s feet. Based on United States Department of Labor, there has been 8 accident with 4 death regarding oil storage tank accident on the year 2017 itself. The accident might not have involved oil and gas FSO tankers, however because of its similar structure, the probability does not diminish. Storage tankers has a history of explosion on their cargo tank. They are mainly trading tankers, however potential always arises.

Table 1 : Cargo tank fire/explosion frequencies on trading tankers

Severity	Events (1980–2013)	Frequency (per tanker year)
Total losses (TL)	17	4.2×10^{-4}
Serious casualties (Excluding TL)	31	7.7×10^{-4}
Serious casualties (Including TL)	48	1.2×10^{-3}
Non-serious incidents	40	1.0×10^{-3}
All events	88	2.2×10^{-3}

3.0 Methodology

3.1 Quantitative Risk Assessment

QRA has been used for offshore operation and is a sophisticated technique that engineers use to predicts various type of risk. In application of health and safety, QRA usage can be classified into categories:

- Estimates long-term risk towards workers and public from exposure to harmful activities.
- Estimates risk to workers and public from sequential events involving a one-time exposure.

Fig. 2 demonstrates the steps in performing QRA. The first stage of the key components is the system definition. The activity whose risk is to be identified is defined to ensure there exist a boundary for the studies. This will minimise the scope and ensure which activities is to be included and excluded. Next is the hazard identification, which is a qualitative analysis to review what are the accidents that could occur, mainly based on past data and history. Then, estimation of frequency analysis is made to find out the unlikeliness for the accidents to happen. The frequencies can be obtained by the previous accident or modelling (Spouge, 1999).

3.2 Preliminary hazard analysis (PHA)

PHA or preliminary hazard analysis is a semi-quantitative analysis (Rausand, 2005). It is used to identify potential hazards and accidents/accidental events, rank events based on their severity and identify the control measure and further actions. Table 2 shows the PHA on a typical FSO crude oil storage tank.

3.3 Estimation of failure frequency

Estimation of failure frequency gives reliability to the distribution of how many times the failure can occur. FTA or fault tree analysis is a tool to analyze, model and assess events that leads to accidents. It can be used for root cause analysis, where all relevant events can be determined with sequence and can also assess the risk level of an undesired event in order to find out the effect after changes in design (Marshall, 2012). Its strength is multiplied with its cause/effect visual model which is easy to read and comprehend because of its nature in following the path of events sequentially. Fig. 3 shows the simplified FTA for crude oil storage tank and explosion in the case of leakage of the crude oil.

Table 2: PHA on storage tank

No.	Hazard	Probable Cause	Severity
1	Storage tank fire/explosion	Leaking	1
		Collision around hull area	1
		Sloshing on floor and wall plates	1
		Internal cracks	1

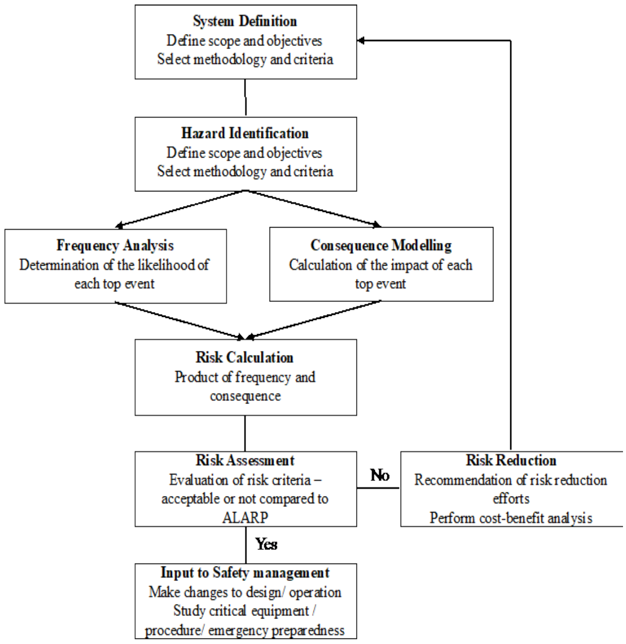

Fig. 2 : Flowchart of QRA

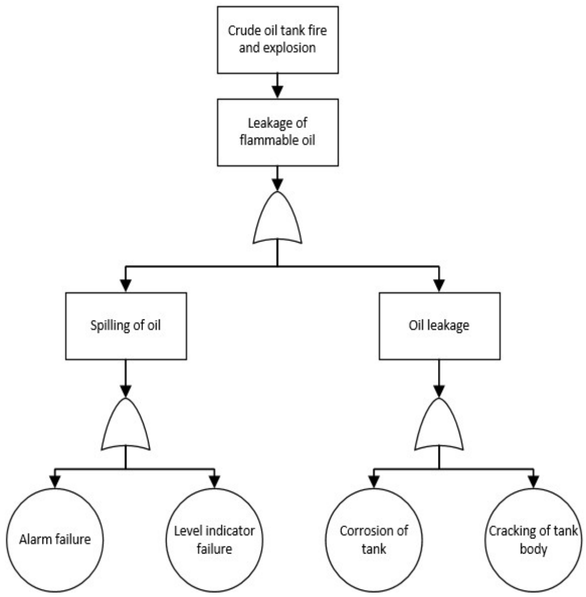

Fig. 3 : FTA for crude oil tank fire and explosion due to leakage

3.4 Consequences Analysis

After hazards are identified, level of risk is calculated. The calculation is targeted to reach the data for crude oil tank fire/explosion. Pool fire happens over a static hydrocarbon spill; hence the diameter of the spill is required. For pool fire, the fatality thermal radiation is within the diameter of 35 m (O'Sullivan et al., 2004). Based on the equation for pool fire, the calculated thermal radiation is as Table 3.

Thomas correlation is used for the pool fire equation diameter and the calculation of heat released by the pool fire (DiNenno et al., 2002).

Pool fire equation:

$$Q = m\Delta Hc\,(1 - exp\,(-K\beta.D))A_{dike} \quad (1)$$

$$A_{dike} = \pi D^2/4 \quad (2)$$

where Q is pool fire heat released (kW), ΔH_c is heat of combustion fuel (kJ/kg), Kβ is empirical constant (m^{-1}), D is pool diameter (m) and A_{dike} is surface area of pool fire (m^2).

Fireball models has been formulated to calculate its duration and diameter (Martinsen et al., 2000). The equation used came from A.F Roberts (Fei Liu et al., 2018) where the diameter relates to the mass of fuel, M (kg), involves in the fireball.

Fireball equation:

Diameter, D (m): $D = 5.8\ M^{0.333}$ (3)

Duration, t_d (s): $t_d = 2.6\ M^{1/6}$ (4)

3.5 Risk Analysis

After calculation of consequence, it is combined with frequency and probability to determine the level of risk for the failure cases. The main purpose of this analysis is to know the individual risk per annum (IRPA) and potential of loss of life (PLL) (Lewis et al., 2007). The equations used are:

Individual risk per annum (IRPA) equation:

$$IRPA = \frac{No.of\ fatalities\ per\ year}{No.of\ people\ at\ risk/\ time\ spent} \quad (5)$$

Potential loss of life (PLL) equation:

$$PLL = IRPA \times POB \quad (6)$$

where POB is number of persons on board.

Table 3 : Pool fire thermal radiation distance

Burning rate (kg/m²s)	0.00335
Heat of combustion (kJ/kg)	42600
Density (kg/m³)	850.8
Empirical constant (m⁻¹)	2.8
A (m²)	490.8313
Q (kW)	371197.2682
X (m)	29.0516

Table 4 : Fireball calculation

Volume (m³)	3273
Density (kg/m³)	850.8
Mass (kg)	2784668
D (m)	811.965
td (s)	30.8391
Radius of spread (m)	405.983

4.0 Results and discussions

4.1 Probability of event

Table 5 shows the frequency of event towards various types of possible explosion scenario. There are three potential escalation probabilities are considered in the analysis, which are no explosion, weak explosion, and strong explosion. The probability of internal explosion assumed are: (1) strong explosion: 10%, (2) weak explosion: 30% and (3) no explosion: 60%. There is a higher frequency in the scenario of no explosion to occur in the crude oil storage tank. Weak explosion has a higher probability of it causing no requirement for temporary refuge because of the lower damage.

4.2 Individual risk per annum (IRPA)

IRPA takes account into the amount of time a person spends in an area in the FSO. The time spent is estimated with the nature of work. Table 6 shows the individual risk per annum on specific personal on a typical FSO. The total PLL per year accounted to 1.125×10^{-5} /year.

Table 5: Frequency of events

Scenario	Frequency of Event
Strong Explosion leading to temporary refuge	1.10×10^{-5}
Strong Explosion, no temporary refuge	1.10×10^{-5}
Weak Explosion leading to temporary refuge	1.65×10^{-5}
Weak Explosion no temporary refuge	4.95×10^{-5}
No explosion	1.32×10^{-4}

Table 6: Individual Risk Per Annum (IRPA)

Worker Category	Fatalities per year (year^{-1})	No. people at risk / time spent	IRPA
FSO Master	1.10×10^{-5}	0.328	3.61×10^{-6}
Maintenance Superintendent	1.10×10^{-5}	0.328	3.61×10^{-6}
Radio Operator	1.10×10^{-5}	0.328	3.61×10^{-6}
Lead Marine	1.10×10^{-5}	0.328	3.61×10^{-6}
Lead Mechanical	1.10×10^{-5}	0.328	3.61×10^{-6}
Lead Deck	1.10×10^{-5}	0.328	3.61×10^{-6}
Marine Technicians	1.10×10^{-5}	0.328	3.61×10^{-6}
Crane	1.10×10^{-5}	0.328	3.61×10^{-6}
Crane Operator	1.10×10^{-5}	0.328	3.61×10^{-6}
Catering Staff	1.10×10^{-5}	0.328	3.61×10^{-6}
SHO	1.10×10^{-5}	0.328	3.61×10^{-6}
CSR	1.10×10^{-5}	0.328	3.61×10^{-6}
Technical Worker	1.10×10^{-5}	0.328	3.61×10^{-6}
Production Technician	1.10×10^{-5}	0.136	1.50×10^{-6}
Wellhead Crane	1.10×10^{-5}	0.136	1.50×10^{-6}

4.3 Risk Evaluation

The total PLL per year accounted to 1.125x10^{-5}. Following the guideline for individual risk of workers, the risk is broadly acceptable, and only consider cost effective alternative (Spouge, 1999). Based on the ALARP tolerable region, the IRPA falls into the tolerable region, and is very close to the acceptable region (Moan et al., 2002). The risks can be tolerated if risk reduction is implanted. Hence, there are several recommendations that can be introduced to lower the risk level.

4.4 Recommendations

Every vessel requires safety to be enforced on its ground. Without a set of rules or security, the wellbeing of the vessel cannot be kept. In order to increase safety of the whole FSO, rules must be enforced towards the visitors and the personnel. Controlling the activities and the limitation of a worker and visitor helps minimize the possibilities of accident. It is a prominent precaution because of the abundance of crude oil and processing facilities that acts as a source of explosion. Even when rules are established, some personnel could find a workaround to do dangerous activities such as smoking. Visitor and third-party contractor might also come to the FSO without the knowledge on the rules on the ship. Patrolling from supervisors and security helps to regulate the activities that occurs on the ship.

The crude oil storage tank must always be in a good condition for the safety of its usage. The most important things that must be overlooked in this case are problems such as leaking, ship collision, slushing and internal cracks. Leaking of the crude oil storage tank must be avoided by the means of constant inspection and maintenance. This can also be applied for the sloshing of the oil in the tank and the internal cracks. However, for ship collision, the rates vary from places to places. More assessment is required to gain the estimates of this collision (The Oil Companies International Marine Forum (OCIMF), 1997).

Crude oil is also susceptible for corrosion. External corrosions are probable mostly due to the exposure to the sea breeze and water of high salinity content. Crude oil itself might also contain high sulphur content which promotes the formation of active corrosion cell ((The Oil Companies International Marine Forum (OCIMF), 1997). To overcome this problem, coating helps in covering the whole surface internally and externally to retard corrosion. Inspection also helps by collecting the corrosion data to understand the trend and the situation.

The emergency team and its equipment play an important role for becoming the first response during an emergency. This is essential in order to prevent any obtained injuries from becoming worse. Some of the emergency that is required on the vessel should consist of emergency first aid, CPR & Automated External Defibrillator (AED) and fire extinguishers. This equipment must be kept in a reachable place and easy to be located during emergency. Intensive course must be provided to all personnel to ensure sufficient knowledge is readily available when the equipment is required to be used. Having the equipment itself would not help if it is not working hence the equipment has to be checked periodically. The vessel requires maintenance and inspection to ensure the facilities can be use in good condition. The reliability of the FSO will affect the risk and the probability of an incident from occurring on the vessel.

5.0 Conclusions

The individual risk and the potential loss of life is considerably low, but it must not be disregarded for the operation offshore. The safety of the personnel on the vessel and the environment is very important as any losses in the form of life or environment has an adverse effect towards all of us. The risk can be further lowered by implementing the recommendations listed in the Section 4.4.

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